# Mine Burial Prediction: A Cooperative NRL/ONR Study

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## LONG-TERM GOALS

To provide the U.S. Navy with an accurate, probabilistic mine burial prediction capability through testing and validation of improved and recently developed, physics-based, mine burial models. The payoff will be an integrated, probabilistic, time-dependent mine burial model which can be applied to tactical and strategic mine burial scenarios.

## OBJECTIVES

Sediment-structure interactions are responsible for the burial/penetration of heavy objects, such as bottom mines, pipelines, stone and concrete breakwater elements, and waste canisters into the seafloor. On seabeds of low shear strength mud, these objects are known to penetrate on impact when the bearing capacity of the seafloor is exceeded, with additional subsequent burial from sediment consolidation and creep. On sand seabeds, burial is common by scour and fill, momentary or cyclic wave-induced liquefaction, and seabed morphological changes (e.g., transverse bedform migration, changes in shore-rise and bar-berm conditions, sediment deposition). Using a field experimental approach, the Naval Research Laboratory (NRL) will test and evaluate physics-based mine burial processes and models in order to provide the US Navy with an accurate, real-time mine burial prediction capability.

## APPROACH

NRL is tasked with development, deployment, and analyses of data from instrumented, cylindrical mine-shapes; conducting impact and subsequent burial experiments; development of an improved impact burial model; and development of an integrated mine burial model. One of the major problems in the experimental validation of mine burial models is the difficulty of continuous measurement of the behavior of the mine. Optically instrumented, cylindrical, subsequent burial mine-shapes, developed by NRL, provided a tool for continuous monitoring of the movement of the shape (heading, pitch and roll), as well as the percentage of the surface area of the shape actually buried (see Richardson et al., 2001; Griffin et al., 2001; Richardson and Traykovski, 2002). The next generation acoustically instrumented, subsequent burial mine-shapes were developed by OMNI Technologies Inc. under the direction of NRL as part of a Small Business Innovative Research initiative and have or have the potential to extend that monitoring capability to characterize developing scour pits, migrating sand dunes or ripples; quantify the boundary layer flow around the shape; measure sediment concentrations and flux in the vicinity of the shape; measure sea state and bottom currents; determine initiation of bed

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14. ABSTRACT
**To provide the U.S. Navy with an accurate, probabilistic mine burial prediction capability through testing and validation of improved and recently developed, physics-based, mine burial models. The payoff will be an integrated, probabilistic, time-dependent mine burial model which can be applied to tactical and strategic mine burial scenarios.**

15. SUBJECT TERMS

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load transport; and calculate sediment transport (Griffin et al., 2002; See Griffin et al., this CD). An instrumented, cylindrical, impact burial mine-shape was also developed for impact burial experiments and is capable of monitoring shape motion during free-fall across the air-water interface, through the water column, and into the seabed sediments (three accelerations and three angular velocities) (Valent et al., 2001, 2002).

NRL leads the effort to improve the Impact Burial Prediction Model using data collected in tank and field tests during FY01-04 and is responsible for improving and validating the sediment penetration module and for integrating a hydrodynamic module and stochastic relevance into a final impact burial model. Field experiments on burial by scour and fill; bedform migration; bedform morphological alterations; liquefaction or fluidization of the sediment; and biological processes were conducted in the winter of 2002-3 off Tampa Bay and for the Martha's Vineyard Coastal Observatory (MVCO) during the winter of 2003-4. For all these experiments, NRL was responsible for: (a) deployment and analyses of data from instrumented mine-shapes, (b) quantification of environmental processes in the near field of the cylinders, and (c) characterization of mine-shape movement and burial. These data will allow development and validation of new and proposed mine burial models.

Advances in our physical understanding of mine burial and the new mine burial models resulting from these joint experiments, including NRL modifications to the impact burial model, will be integrated into a framework for a stochastic approach to mine burial prediction. This model recognizes that mine or object burial is time dependent, spatially and temporally variable and that burial processes are not independent (Richardson et al., 2001). The integrated mine burial model will require as input: (a) wave climate and tidal and storm-induced bottom currents from in situ measurements or numerical oceanographic models, (b) sediment physical properties and small-scale morphological feature description from in situ measurements or historical databases, and (c) description of the anticipated mine threat. The model (preliminary version completed in 2004 and tested in FY05) will provide both strategic and tactical mine burial prediction. NRL will also assess the effects of uncertainties in the input parameters for predictions of mine burial at impact and by subsequent burial through stochastic simulations involving most free parameters. This differs from a sensitivity analysis where typically the effect of one variable is found throughout its variation. With stochastic simulations, all variables can vary and the model's convolution of the uncertainty through its nonlinearity can be addressed.

## WORK COMPLETED AND RESULTS

***Impact Burial Experiments:*** Impact burial experiments were conducted during May 2002 along the Texas continental shelf near Corpus Christi, Texas and June 2003 and June 2004 on the delta of the Mississippi River. NRL provided diver support for the experiments, collected gravity cores for subsequent ship-board and laboratory analyses of sediment geotechnical and physical properties, measured in situ shear strength with a STING penetrometer, and deployed an instrumented, cylindrical mine-shape specifically designed by NRL and OMNI Technologies for these impact burial experiments. The motion of the cylindrical shape, from the moment of deployment through embedment in the seafloor, was characterized using data collected from the 3-axis fiberoptic gyro (roll, pitch and heading) and 3-axis accelerometers and magnetometers (movement through space - x,y,z) within the instrumented cylinder. NRL developed software to analyze this complex motion. Much of the mine-shape motion data was given to ONR modelers (see paper by Kim, Y., et al., in preparation) and the remainder will be disseminated as soon as quality control of the data is complete. Sediment cores have been logged (sound speed, attenuation and bulk density) at the NRL laboratory facilities and opened

for visual inspection; shear strength was measured with a motorized laboratory vane; and subsamples were collected for measurement of natural water content, grain and bulk density, and grain size distribution. These values of sediment physical and geotechnical properties, together with the 6-degrees of motion of the mine-shape are being used to evaluate prediction capability of the current impact burial model (IMPACT28) and to develop improvements to that model. (This NRL work on the impact burial experimentation and model development is conducted in close collaboration with the ONR Mine Burial Program, but, for FY03 and 04, has been funded only by NRL's 6.2 Base Program.)

***Subsequent Burial Experiments (MVCO, IRB)***: Subsequent burial experiments (ONR-MBP Program) were conducted in the shallow water area off Tampa Bay Florida (Winter 2002-3) at the WHOI Martha's Vineyard Observatory (Winter 2003-4). During FY03, NRL completed development and testing of the instrumented mine-shapes (with OMNI Technologies) used for those experiments. The original NRL instrumented mine-shape was successfully deployed at the Martha's Vineyard Observatory three times during 2002-03. The shape was hard-wired (power and data transfer) using nodes provide by WHOI at 12-m water depth. Real-time burial data (cylinder movement and percent burial) was collected, as well as sector scan sonar images (1.3 MHz) of the burial process, and wave and currents using ADCPs and bottom mounted pressure sensors. The comparison of burial results to scour model predictions are very encouraging (Richardson, M.D., P. Traykovski and C.T. Friedrichs, in preparation; Elmore, P.A. and M.D. Richardson, 2003, Richardson, M.D. and P. Traykovski. 2002). Mine-shape burial studies at the Indian Rocks Beach site are in the final stages of analysis (Bower yet al, 2003). Mine-shape movement (heading, roll and pitch) have been analyzed and pressure sensor data use to characterize tidal conditions, cylinder movement and surface gravity wave significant heights. Analysis of changes in percent burial (sensors covered) and scour pit development have also been made. Two or three significant burial events were recorded where mine-shapes pitched, rolled into the scour pit while changing heading with respect to ocean wave conditions. These events corresponded to the highest significant wave events and are generally in good agreements with real-time and post scour burial predictions. Preliminary results were presented at the Oceans 2003 conference in San Diego CA (Richardson et al., 2003) and are the subject of a NRL report (Bower et al, 2003). Preliminary results from the Martha's Vineyard (Winter 2003-04) have been completed and the results presented at the 6$^{th}$ International Symposium on Technology and the Mine Problem. Naval Postgraduate School, Monterey, California, 9-13, May 2004 (Elmore and Richardson, 2004; Richardson et al, 2004, Trembanis et al, 2004; Traykovski et al, 2004; and Bower et al, 2004).

***Mine Burial Model Development***: Development and validation of deterministic and stochastic mine burial models (including expert systems) is being carried out using NRL 6.2 core funding and are therefore beyond the scope of this proposal.

***Data Dissemination and Publications***: All ONR investigators are provided with data from the instrumented mine-shapes and laboratory sediment characterization as soon as it is available (after quality control checks) and do not have to wait for NRL data reports or publications. Preliminary data for the subsequent burial experiments on mine-shape burial and orientation have typically been made available within two months of the end of the deployment. Description of near field processes (mean and turbulent flow, sediment concentrations, and sediment transport) will take longer to analyze. It is hoped that other ONR investigators will participate in that analyses. Results from the instrumented mine burial and sediment characterization has been made available on the ONR Mine Burial Web site. NRL will publish the results in peer-reviewed journals. Joint publications with other ONR investigators are encouraged.

## IMPACT/APPLICATIONS

Buried mine detection has been and is still one of the greatest threats facing shallow water Mine CounterMeasures (MCM) operations. The possible presence of buried mines can change MCM tactics from mine hunting to minesweeping or area avoidance. The ability to predict mine burial both for planning and during operations (strategic and tactical scenarios) is therefore of great importance to Naval forces.

## RELATED PROJECTS

All ONR projects in the Mine Burial Prediction Program (http://www.mbp.unh.edu/front/index.cfm ).

## REFERENCES AND PUBLICATIONS (2001-2004)

### Peer-reviewed articles in periodicals and in books

Griffin, S., J. Bradley, M.D. Richardson, K.B. Briggs and P.J. Valent, 2001. Instrumented mines for mine burial studies. *Sea Technology,* **42 (11)***:21-27.*

Holland, K.T., A.W. Green, A. Abelev and P.J. Valent (accepted for publication, July 2004). Parameterization of the in-water motions of falling cylinders using high-speed video. *Experiments in Fluids*

Kim, Y., Y. Liu, D.K.P. Yue and K.T. Holland (submitted). On the Dynamics of a Three-Dimensional Body Falling Through Water. *Journal of Fluid Mechanics.*

### Published Proceedings

Richardson, M.D., P.J. Valent, K.B. Briggs, J. Bradley, and S. Griffin, 2001. NRL Mine Burial Experiments, *Proceedings of the Second Australian-American Joint Conference on Technologies of Mine Countermeasures*, Sydney, Australia, March 2001.

Richardson, M.D., and P. Traykovski, 2002. Real-time observations of mine burial at the Martha's Vineyard Coastal Observatory, *Proceedings of the 5th International Symposium on Technology and the Mine Problem*, Monterey, CA, May, 11p.

Valent, P.J., K.T. Holland, A.W. Green. S. Theophanis, M.D. Richardson, G.D. Bower, P. Congedo and W. Lewis, 2002. Observations of velocities and orientation of cylindrical bodies at terminal condition in water, *Proceedings of the 5th International Symposium on Technology and the Mine Problem,* Monterey, CA, May.

Griffin, S., J. Bradley, M. Thiele, C. Tran, F. Grosz and M.D. Richardson, 2002. An improved subsequent burial instrumented mine, *IEEE-MTS Oceans 2002*, Biloxi, MS, October.

Abelev, A.V., P.J. Valent, N.G. Plant and K.T. Holland, 2003. Evaluation and Quantification of Randomness in Free-fall Trajectories of Instrumented Cylinders, *Proceedings, IEEE-MTS Oceans 2003*, San Diego, CA, September.

Elmore, P.A., and M.D. Richardson, 2003. Assessing Scour Model Performance with Experimental Data, *IEEE-MTS Oceans 2003*, San Diego, CA, September.

Abelev, A.V., and P.J. Valent, 2004. Dynamics of bottom mine burial in soft sediments: experimental evidence and predictions, *3rd Joint Australian-American Conference on Mine Countermeasures and Demining*, Canberra, AUS, February, 18p.

Barbu C., P. Valent, M.D. Richardson, A. Abelev and N. Plant, 2004. A probabilistic approach for mine burial prediction, *SPIE Defense and Security Symposium*, Orlando, Florida, April, 8p.

Abelev, A.V., P.J. Valent and C. Barbu, 2004. Risk assessment and implementation of impact burial prediction algorithms for detection of bottom sea mines, *Proceedings of the 6th International Symposium on Technology and the Mine Problem*, Monterey, CA, May, 15p.

Bower, G.R., M.D. Richardson, K.B. Briggs, P.A. Elmore, C.S. Kennedy, P.J. Valent, D.F. Naar, S.D. Locker, P. Howd, A.C. Hine, B.T. Donahue, J. Broderson, T.F. Wever, R. Luehder, C.T. Friedrichs, A.C. Trembanis, S. Griffin, J. Bradley and R.H. Wilkens, 2004. Mine burial by scour: Results from the Gulf of Mexico, *Proceedings of the 6th International Symposium on Technology and the Mine Problem*, Monterey, CA, May.

Elmore, P.A., and M.D. Richardson, 2004. Regional mine burial prediction using Monte Carlo and deterministic methods, *Proceedings of the 6th International Symposium on Technology and the Mine Problem*, Monterey, CA, May.

Richardson, M.D., E.F. Braithwaite, S. Griffin, J. Bradley, C.T. Friedrichs, A.C. Trembanis and P. Traykovski, 2004. Real-Time Characterization of Mine Scour Burial at the Martha's Vineyard Coastal Observatory, *Proceedings of the 6th International Symposium on Technology and the Mine Problem*, Monterey, CA, May.

Traykovski, P., M.D. Richardson, J.A. Goff, L.Mayer, R. Wilkens and B. Gotowoka, 2004. Mine burial experiments at the Martha's Vineyard Coastal Observatory, *Proceedings of the 6th International Symposium on Technology and the Mine Problem*, Monterey, CA, May.

Trembanis, A.C., C.T. Friedrichs, M.D. Richardson, P. Howd and P. Traykovski, 2004. Real-time forecasts of mine scour burial at Indian rocks Beach, Florida and Martha's Vineyard, Massachusetts, *Proceedings of the 6th International Symposium on Technology and the Mine Problem*, Monterey, CA, May.

**Published Abstracts**

Briggs, K.B., P. Elmore, C.T. Friedrichs, P. Traykoviski and M.D. Richardson, 2002. Predicting Mine Burial at the Martha's Vineyard Coastal Observatory, *Eos. Trans. AGU,* ***83(7),*** Fall Meeting Supplement, Abstract OS61A-0185.

Traykoviski, P., and M.D. Richardson, 2002. Observations of Bedforms and Mine Burial Processes at the Martha's Vineyard Coastal Observatory, *Eos. Trans. AGU,* ***83(7),*** Fall Meeting Supplement, Abstract OS61A-0184.

Elmore, P.A., and M.D. Richardson, 2003. Scour Modeling for Mine Burial Prediction: a Sensitivity Study of Model Coefficients, Oceanology 2003, *Oceanography* **16(2)**:37.

Richardson, M.D., P.A. Elmore, K.B. Briggs, G.R. Bower, C.S. Kennedy, S. Griffin and J. Bradley, 2003. Mine burial by scour, Oceanology 2003, *Oceanography* **16(2)**:56.

Richardson M.D., and P. Traykovski, 2003. The evolution of rippled seafloor topography with acoustic implications, *Journal of the Acoustical Society of America*, **113 (4):**2299. (invited).

Richardson, M.D., G.R. Bower, K.B. Briggs, P.A. Elmore, C.S. Kennedy, P.J. Valent, D.F. Naar, S.D. Locker, P. Howd, A.C. Hine, B.T. Donahue, J. Brodersen, T.F. Wever, R. Luehder, C.T. Friedrichs, A.C. Trembanis, S. Griffin, J. Bradley and R.H. Wilkens, 2003. Mine Burial by Scour: Preliminary results from the Gulf of Mexico, *IEEE-MTS Oceans 2003*, San Diego, CA, September.

Friedrichs, C.T., A.C. Trembanis, M.D. Richardson, P.A. Elmore, P. Traykovski and P.A. Howd, 2004. Predicting Scour-Induced Burial of Cylinders within Energetic Shelf Settings: Evaluating a Parameterized Forecasting Model, *Eos "Ocean Sciences Meeting",* Portland OR, January.